

# Analysing the Effect of Heat Treatment & Ageing on the Properties of Al 7075

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**ABSTRACT:** Aluminium 7075 is one of the most widely used aluminium alloy in various industries as it possesses high tensile strength, yield strength, impact strength and some other properties. A large part of overall consumption of Al 7075 is used in aviation industry and then automobile industry. To increase the applications of this alloy the properties must enhance as compared to their present standards. To enhance the properties of the alloy some processes can be used as heat treatment, strain hardening, cryo-rolling etc. These processes can enhance the alloy properties significantly as the temperature greatly affects the properties of aluminium alloy. In the present work heat treatment process is chosen to analyze and characterize the change in alloy properties. Along with the mechanical properties, micro-structural evaluation has also been performed to distinguish the change in microstructure in accordance with the change in alloy properties. The heat treatment of the alloy resulted in increasing the alloy properties significantly. As a result of heat treatment the quenching process imparted significant increment in the alloy properties as compared to other heat treatment processes. For ageing treated samples the ageing temperature of 140°C imparted the best properties but as the temperature increased the property enhancement started to decrease. It was clear from the present work that heat treatment process can significantly enhance the properties of aluminium 7075 alloy.

**KEYWORDS:** Al 7075, Heat Treatment, Ageing, Tensile Properties, Impact Strength

## I. INTRODUCTION

As aluminium is present in abundance in the earth's crust and because in its alloying state it possesses some good combination of mechanical and other properties, aluminium is one of the most widely used metals[1]. Some of those properties are ductility, malleability, (Al is the second most malleable and the sixth most ductile metal[2]), good strength-weight ratio, excellent thermal and electrical conductivity, recyclability, non toxic (as used in food packaging), good corrosion resistance etc. with such exceptional properties the uses of aluminium and its alloys are also widespread. Al alloys find major portion of their applications in automotive and aerospace industry, construction and building, containers and packaging, electrical and heat transfer engineering and much more. Possessing properties such as good strength, corrosion resistance, low weight while being cost effective at the same time is a primary reason for ever increasing demand of Al alloys in the aerospace and automotive industry. According to a report by the European Aluminium Association, the amount of aluminium used per car produced in Europe almost tripled between 1990 and 2012, increasing from 50 kg to 140 kg. This amount is predicted to rise to 160 kg by 2020, and could even reach as much as 180 kg.

The elements commonly used to alloy with aluminium are zinc (Zn), magnesium (Mg), Cu and Si which have significant solubilities and several other elements with low solubilities also confer improvements to alloy properties. Some transition metals like chromium (Cr), manganese (Mn) and zirconium (Zr) are primarily used to form compounds that control the grain structure[3]. The very basic classification of Al alloys is based on their fabrication process and they are classified either as cast or wrought alloys[4]. One group consists of those alloys in which the mechanical properties are controlled by work hardening and annealing, like commercially pure Al and alloys based on Al-Mg and Al-Mn. Whereas the second group consists of the alloys which respond to precipitation hardening. Both of the categories are further subdivided into heat-treatable and non-heat-treatable. In wrought alloys only 2xxx\*, 6xxx\*, 7xxx\* series alloys are heat treatable whereas the other alloys are non heat treatable. For heat treatable alloys strain

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hardening may supplement the strength developed by precipitation hardening whereas for non heat treatable alloys strain hardening provides strength to the alloys via dislocation interaction. Aluminium alloy 7075 (Al 7075) is an aluminium alloy with zinc as its primary alloying element. Al 7075 has been introduced by Alcoa in 1943[5] (there is a contradiction associated with the origin of Al 7075 as according to Japan Aluminium Association the first Al 7075 alloy was developed in secret by a Japanese company sumitomo metal in 1936 and it was used for the Mitsubishi A6M zero fighter's air frame for the Imperial Japanese Navy starting in 1940). Ever since it has been the standard workhorse 7XXX series alloy within the aerospace industry. It was the first successful Al-Zn-Mg-Cu high strength alloy which used the beneficial effects of the alloying addition of chromium. The strength of this alloy is comparable to many steels and it has good fatigue strength but average machinability. Al 7075 has less resistance to corrosion compared to other Al alloys as various other 7XXX alloys have been developed since Al 7075 with improved specific properties, but Al alloy 7075 remains the baseline with a good balance of properties required for aerospace applications. But the high cost associated with Al 7075 limits its use to applications where cheaper alloys are not suitable.

## II. MATERIAL AND TESTING

The Al 7075 alloy was procured from Bharat Aerospace Materials Ltd. The composition of aluminium alloy 7075 is-

TABLE 1 Composition of Al 7075

Element	Zn	Mg	Cu	Mn	Fe	Si	Cr	Ti	Al
Weight %	5.8	2.5	1.6	0.28	0.40	0.35	0.21	0.19	Balance

### 2.1 Test Specimen Preparation

The samples for tensile testing were cut according to ASTM E8 standards and impact testing samples were cut out according to the ASTM E23 standards.

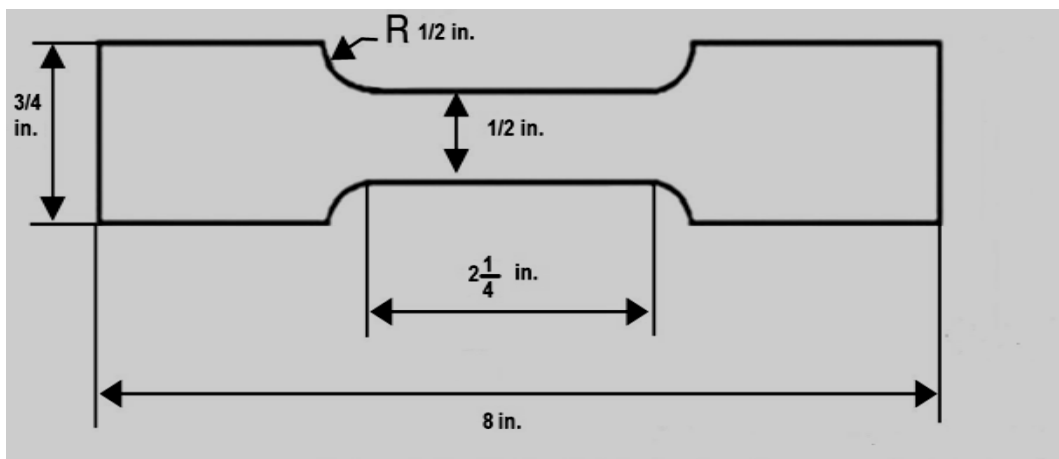


Fig.1 Rectangular tension test specimen

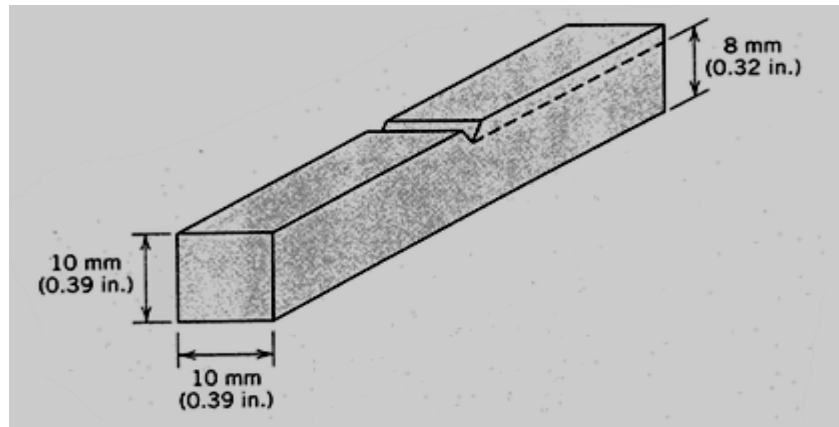


Fig.2 Impact Test Specimen

## 2.2 Heat Treatment

In present study heat treatment of Al 7075 is done to investigate the mechanical properties and fracture toughness of the material. Certain heat treatment processes were used to enhance the properties of the material. Heat treatment process was done in a temperature controlled muffle furnace. The samples were heated upto solutionizing temperature for the duration of 3 hours. The solutionizing temperature was taken as 510 °C which was based on various literatures.

### 2.2.1 Quenching

After heating the samples upto solutionizing temperature (510 °C) for 3 hours, samples were taken out of the furnace and quenched in water.

### 2.2.2 Annealing

When the temperature reached at solutionizing temperature of 510 °C for 3 hours, the samples were cooled in the furnace at the rate of 40 °C per hour.

### 2.2.3 Normalizing

When the samples were heated upto solutionizing temperature (510 °C) for 3 hours, the samples were taken out from the furnace and left to cool in the air at room temperature.

### 2.2.4 Ageing treatment

After heating the samples upto solutionizing temperature of 510 °C for 3 hours, the samples were gradually cooled upto different temperatures of 140 °C, 180 °C and 220 °C and maintained at those temperatures for 36h, 24h, 12h respectively.

## 2.3 Tensile Testing

Tensile test Specimens of “Dog Bone Shape” were prepared according to ASTM E8 standards as shown in figure 1. The tensile tests were carried out in a 1000 KN universal testing machine connected to computer to draw the load–displacement curves. The tensile strength, yield stress and elongation were calculated from that data. The tests were performed at room temperature.

## 2.4 Impact Testing

Impact test samples were made according to the ASTM E23 standards as shown in figure 2. The impact tests performed were charpy impact tests. All the tests were performed at room temperature.

### 2.5 Micro-Structural Evaluation

After performing various heat treatments and testing the material properties, micro-structural studies were performed to understand the analogy between micro-structural properties and mechanical properties of the alloy due to various heat treatment operations.

## III. RESULTS AND DISCUSSION

### 3.1 Mechanical Properties

In present discussion the mechanical properties acquired through tensile tests and impact tests are reported. The mechanical properties of the tensile specimen were measured by universal testing machine and impact energy was measured by charpy impact tests.

The properties of the Al 7075 alloy used in present investigation are

TABLE 2 Properties of Al 7075

Tensile strength	254.36 MPa
Yield strength	132.45 MPa
% elongation	9-11%

#### 3.1.1 Tensile Test Properties

The tensile tests were performed in a 1000 KN universal testing machine and the data of the test received from a computer attached to the UTM. From the tensile test the values of tensile strength, yield strength, elongation were reported. For each process three samples were made. The results shown here are the average of three different tests performed for each process. The following table lists the mechanical properties attained from tensile tests viz. Tensile strength, yield strength, % elongation of Al 7075.

After performing normalizing treatment the mechanical properties were increased as compared to the alloy without heat treatment. The achieved tensile strength was 376.64, yield strength 216.82 and the elongation was 13.67%, which are quite greater than the as fabricated alloy. The annealed samples showed good elongation but the increase in tensile and yield strength was not significant. As a result of quenching the mechanical properties of the samples were substantially increased. The material showed enhanced tensile strength (543.75MPa) and yield strength (377.21MPa). As the ageing samples were gradually cooled, after heating upto 510 °C, to the temperature of 140 °C and then heated at 140 °C for 36 h. As a result of this prolonged heating the samples showed increased elongation and other mechanical properties also showed good results as compared to annealed samples. As the ageing temperature and ageing duration were changed from 140 °C for 36 h to 180 °C for 24 h, the tensile properties of the samples deteriorated somehow and came around the premises of annealed samples except for yield strength, which was higher. After ageing at 220 °C for 12h the mechanical properties of the samples suddenly dropped to the extent of as fabricated alloy samples.

Table 3 Tensile Test Results

Process	Ultimate Tensile Strength (MPa)	Yield Strength (MPa)	% Elongation
Normalizing	376.64	216.82	13.67
Annealing	291.35	138.92	18.33
Quenching	543.75	377.21	10.67
140 °C for 36 h	339.73	177.56	19
180 °C for 24 h	298.50	152.96	17.5
220 °C for 12 h	252.05	147.7	16

### 3.1.2 Comparison Of Heat Treatment Processes

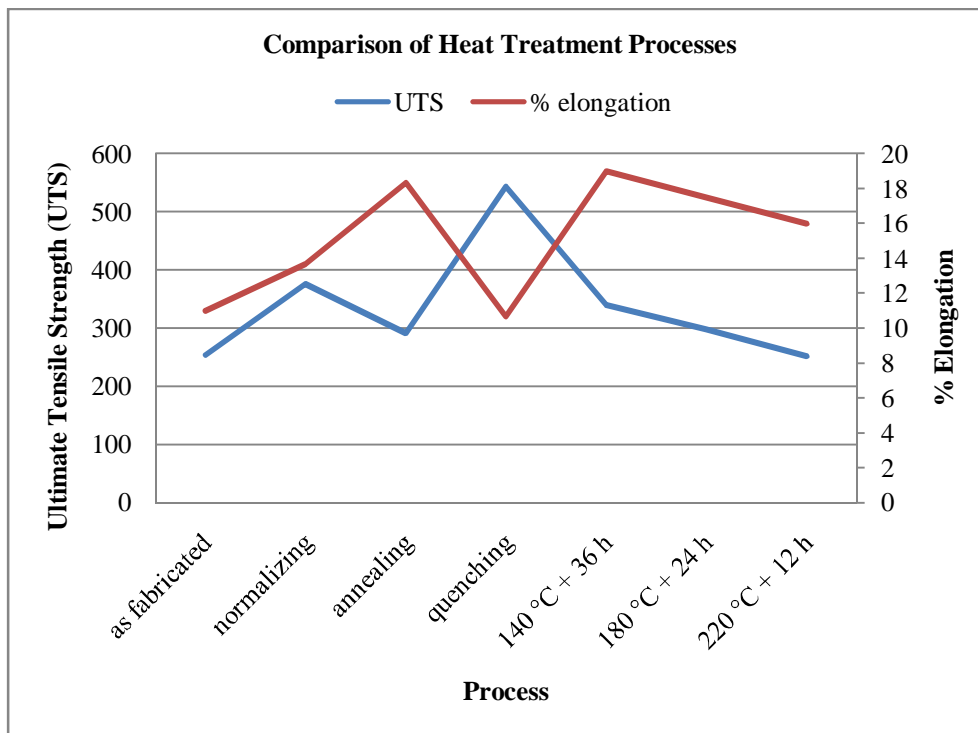


Fig. 3 Process vs. UTS & % Elongation of all heat treatment processes

On comparing all of the above mentioned processes, based on the experimental data, the tensile properties of the quenched samples stand higher than any of the other processes which also is in agreement with various literatures. Yield strength of the quenched samples is also higher as compared to other processes. In case of strain(%elongation) the samples which were aged at 140 °C for 36 h showed the highest elongation percentage along with the annealed samples followed by samples at 180 °C for 24 h, 220 °C for 12 h, normalized samples and quenched samples.

### 3.1.3 Properties Of Aged Samples

As for the ageing treatment, the ultimate tensile strength of the material depends largely on the ageing temperature and varies accordingly with it. In presently investigated aged samples the ultimate tensile strength behaviour indicated a decreasing pattern with the increasing temperature and the increasing time duration of ageing.

### 3.1.4 Impact Behaviour

All the impact test samples were made according to ASTM E23 standards as shown in figure 2. The size of the samples was taken as 55x10 mm. The impact tests were performed at room temperature. According to the results the impact energy of the samples increased as the ductility of the samples increased. The impact energy of the as received sample was around 16J which increased upto 23J for annealed sample which is about 43% increase in the impact energy of the samples. Whereas for the samples aged at 140°C for 36h the impact energy was highest at 26J which is about 60% increase in the impact energy of the heat treated samples.

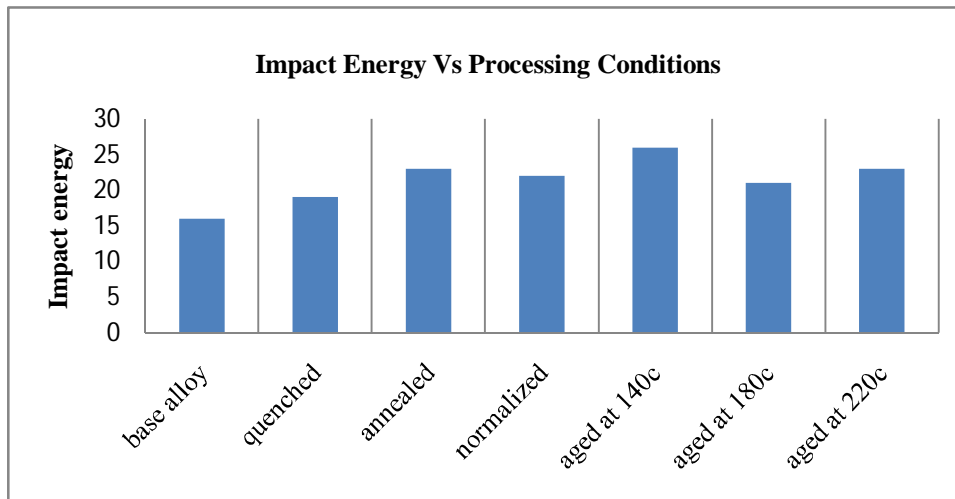


Fig. 4 Impact energy vs. Processing conditions of heat treated samples

### 3.2 Micro-Structural Evaluation

Microstructures help in understanding the mechanical behaviour of the material by providing a basis to characterize the properties of the material in accordance with the corresponding changes in their microstructures. After performing heat treatment the samples were taken through the process of sample selection, grinding, polishing. Etchant was not used as the microstructure was clearly visible without it. The micro-structural morphology was then characterized by optical microscopy. The results of micro-structural study of heat treated samples are presented here.

In the microstructure of the annealed samples the presence of  $MgZn_2$  phase in aluminium matrix is evident. The  $MgZn_2$  phase present consisted of coarse grains which were distributed non-uniformly in the aluminium matrix. When the microstructures of the normalizing samples were analyzed, the presence of micro-segregations of  $MgZn_2$  in aluminium matrix was found. In a study on evolution of eutectic structures in Al-Zn-Mg-Cu alloys, several coarse intermetallic phases such as  $MgZn_2$ ,  $Al_2Mg_3Zn_3$ ,  $Al_2CuMg$ ,  $Al_2Cu$ ,  $Al_7Cu_2Fe$ ,  $Mg_2Si$  and  $Al_{13}Fe_4$  were formed during solidification of 7000 series of aluminium alloys as a result of solute redistribution of metals[6]. The present analyses of finding microsegregation of  $MgZn_2$  in 7075 Al alloy lies in accordance with the previous findings. The increased strength of the normalized samples can be attributed to the presence of these micro-segregations. Microstructure of quenched samples revealed that  $MgZn_2$  phase was present in aluminium matrix. But the grains were non-uniformly distributed in the region. The reason of the presence of this  $MgZn_2$  phase in aluminium matrix was that in a rapidly cooled sample solute redistribution of Mg and Zn is not possible so as a result micro-segregation of  $MgZn_2$  is not formed. In the samples aged at 140 °C for 36h the microstructure showed fine grains with uniformly distributed structure. In the present samples the precipitate of  $MgZn_2$  were found in aluminium matrix. The micro-segregations formed due to gradual cooling are dissolved during the ageing period of heat treatment operations and a homogeneous phase is formed, furthermore the micro-segregations disappear after subsequent cooling. A previous study showing the reduced degree of micro-segregation due to the solution treatment of 2024 wrought aluminium alloy has been reported which supports our present findings of the elimination of micro-segregations after annealing and ageing heat treatment operations[7]. According to the micro-structural study of the samples aged at 180 °C for 24h the precipitates of  $MgZn_2$  phase were present all over the structure. The grains were coarse and their size was large. But these large and coarse grains were distributed uniformly over the entire region of aluminium matrix. As the microstructure of samples aged at 220 °C for 12 h depicts that the grains of  $MgZn_2$  precipitates have become coarse due to the increased ageing temperature. The microstructure of the present samples showed that the coarse grains of  $MgZn_2$  precipitates were non-uniformly distributed over the aluminium matrix.

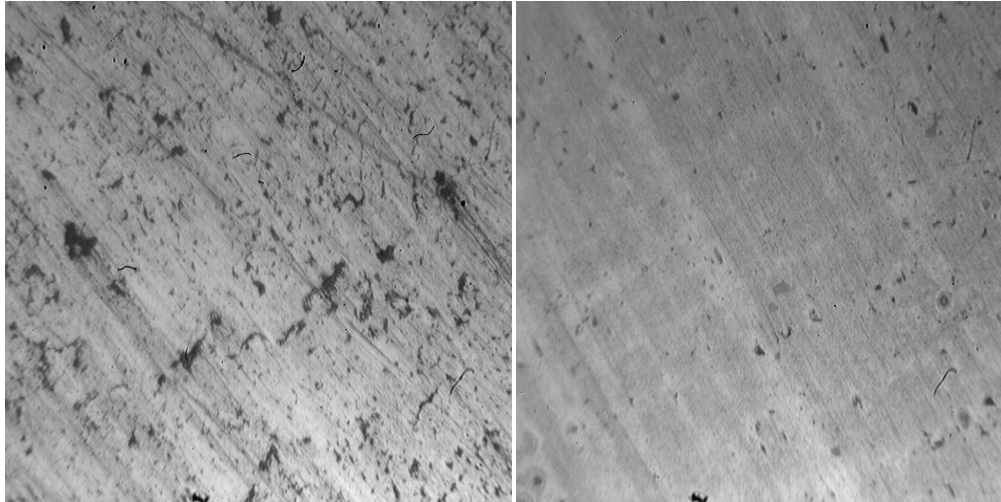
Following are the microstructure images of the different heat treated samples. An Optical Microscope was used to take these images.

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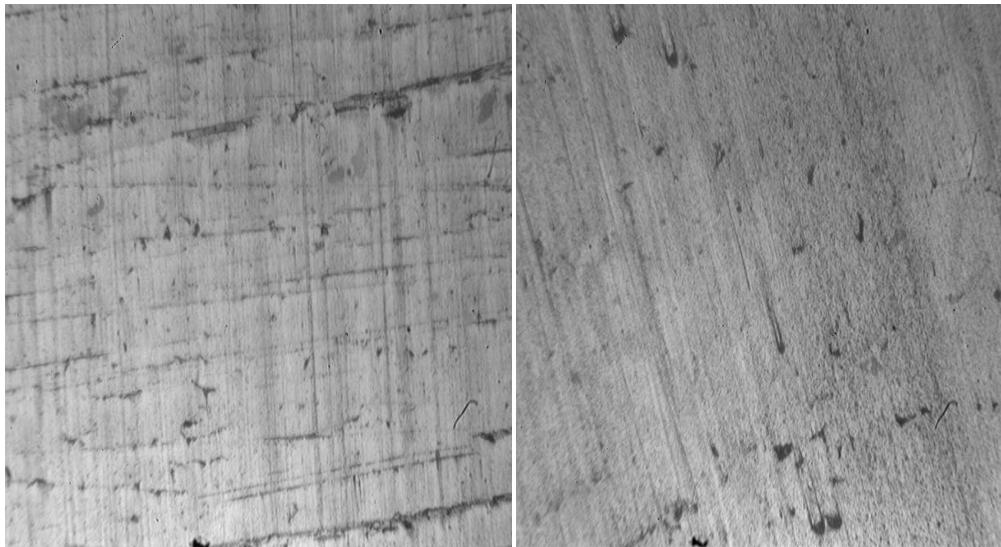
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(a)

(b)



(c)

(d)

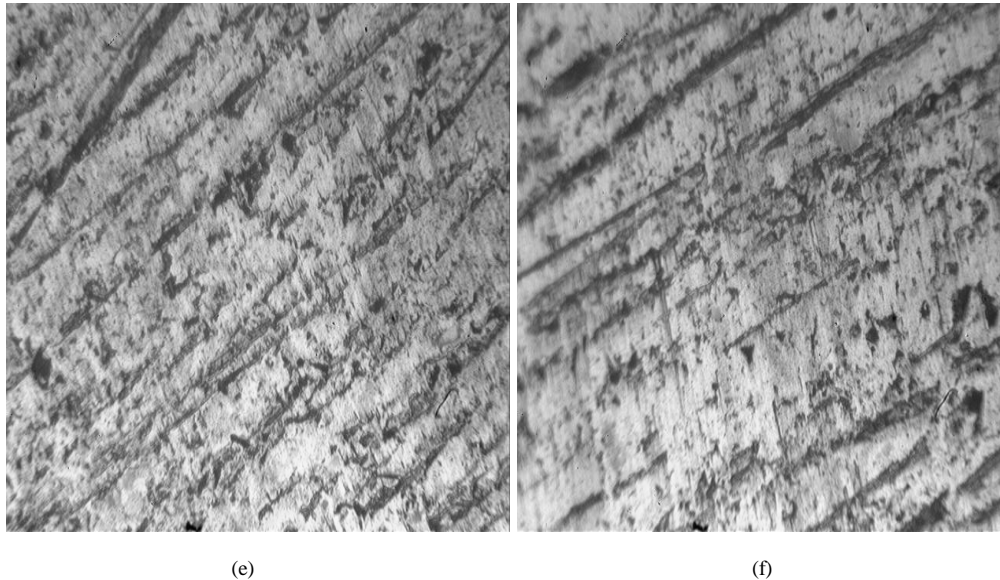


Fig. 5 Microstructural image of (a) Annealed sample (b) Normalized sample (c) Quenched sample (d) Sample aged at 140 °C for 36 h (e) Sample aged at 180 °C for 24h (f) Sample aged at 220 °C for 12h

#### IV. CONCLUSION

In the present work heat treatment of aluminium 7075 was performed and the mechanical properties were characterized on the basis of tensile and impact tests. After performing above tests the microstructures of the samples were observed to determine the relation between mechanical properties and microstructures of the samples. On comparing the properties and characteristics of the heat processed samples the following conclusions are made-

1. After performing heat treatment processes and ageing at various temperatures for different time hours it can be concluded that quenched samples possessed the maximum tensile strength whereas the annealed samples possessed the lowest. In case of only aged samples the temperature of 140 °C greatly affected the tensile behaviour of samples in a positive way. Samples processed at 140 °C showed the highest tensile strength, decreasing as the temperature increased, with 220 °C showing the lowest.
2. As for the yield stress of the samples the quenched samples showed highest yield stress whereas the annealed samples possessed lowest yield strength. For the aged samples temperature range of 140 °C imparted highest yield strength which decreased in an increasing order showing the lowest yield strength in samples aged at 220 °C.
3. Elongation of the samples increased as the cooling time was increased upto a certain temperature. The annealed samples possessed the highest percentage of elongation which was around 20% while the quenched samples possessed the lowest percentage of elongation (10%). As for the aged samples processing temperature of 140 °C for 36 h imparted highest elongation percent to the sample whereas samples processed at 220 °C for 12 h showed the lowest elongation percent.
4. Impact strength of the aged samples increased greatly as compared with other heat treated samples. Ageing at 140 °C for 36 h imparted highest strength as compared with other ageing processes. As for heat treated samples, annealed samples possessed higher impact strength and also close to aged samples.
5. The micro-structural study of the samples showed that the micro-segregation of MgZn<sub>2</sub> phase played an important role to the property enhancement of the samples. The increased tensile strength and yield strength of normalized samples are a result of this micro-segregation.
6. In annealed samples the MgZn<sub>2</sub> phase was present but the grains were coarse and were distributed non-uniformly over the aluminium matrix. This resulted in the low strength behaviour of annealed samples.



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7. As the micro-structural study of the aged samples was performed, the samples aged at 140 °C for 36 h showed that the fine grains of MgZn<sub>2</sub> precipitates distributed uniformly over the aluminium matrix resulted in imparting good strength and elongation to the samples whereas in other ageing temperatures the grains became coarse and their distribution was non uniform which resulted in decreased strength and elongation properties of the samples.

So, concludingly heat treatment certainly imparted good properties to the Al 7075 alloy. All the processes showed improved properties as compared to the base alloy. In aged samples strength increased but the strain increased much significantly. The quenched samples, of all the samples, showed a significant increase in the properties.

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